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COMPARING EDGE COORDINATION FEATURES AND MESSAGE DELIVERY IN DISASTER RESPONSE NETWORKS UNDER INTERMITTENT CONNECTIVITY

Divya Vishwanath* & Paul Johnson Asamoah**
* Janardhan Rai Nagar Rajasthan Vidyapeeth, Udaipur, Rajasthan, India
** Power Life University College, Accra, Ghana, West Africa

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Abstract:

This analysis examines how operational continuity and routing configuration shape message delivery in disaster communication networks under intermittent connectivity. A descriptive reanalysis uses 12 published simulation scenarios from 2021, pairing six routing algorithms across two battery service conditions. Paired differences, conditional group means and an exploratory sample restriction distinguish operational responsiveness from routing feature contrasts. Battery swapping exceeds charging across all algorithms, with an average delivery advantage of 23.85 percentage points. Algorithms with listed predictability outperform their comparison group by 34.45 percentage points under swapping but only 0.85 under charging. These conditional differences are consistent with routing information offering greater value when relays remain operationally available. Hop count group contrasts reverse after excluding the timetable-based algorithm, revealing sensitivity to comparison group composition. The contribution separates a recurring operational pattern from configuration comparisons whose interpretation depends on benchmark selection. This distinction refines performance assessment by separating attainable delivery from responsiveness to operational changes. Emergency network planners can apply paired configuration assessments to evaluate continuity arrangements alongside routing choices under comparable operating conditions.

Key Words: Battery Swapping; Delay Tolerant Networks; Descriptive Analysis; Disaster Communication; Routing Configuration

1. Introduction:

Disaster communication depends on whether messages can reach their destinations when conventional connections are unavailable. In networks served by mobile aerial relays, delivery requires coordination between flight schedules, battery service and forwarding decisions. A suitable route may become unusable while a relay recharges, while an available relay may carry messages that cannot progress through subsequent contacts. Cao and Sun, 2013, explain how the store, carry and forward principle enables communication without a continuously connected path. This perspective makes message delivery a joint outcome of operational availability and routing configuration.

Routing decisions address uncertainty about future contacts while allocating limited storage and transmission opportunities. Predictability based approaches use information about delivery prospects to select relays. Hop count-based approaches incorporate message traversal history into forwarding or prioritization decisions. Their value depends on the operating environment and the other features embedded in each algorithm. Sobin et al., 2016, distinguish routing approaches through their forwarding information and replication practices, demonstrating why a protocol designation represents a combination of decisions rather than a single performance attribute. Comparing algorithms by one documented feature therefore requires attention to the configurations assigned to each comparison group.

Battery service introduces a separate operational constraint. Charging suspends relay activity while energy is restored, whereas swapping permits operation to resume after battery replacement. Shorter interruptions may preserve opportunities for message transfer, but the delivery benefit depends on whether the routing configuration uses those opportunities. More frequent contacts can also increase competition for storage and transmission capacity. Silva et al., 2015, identify congestion management as a central challenge in networks with disrupted connectivity. The resulting theoretical expectation is conditional: improving relay availability may support delivery, while the magnitude of that improvement depends on forwarding and resource management.

The closest empirical evidence directly combines aerial routing algorithms with alternative battery service arrangements. Udroiu et al., 2021, report delivery outcomes for six algorithms under swapping and charging in a simulated network informed by preliminary flight measurements. Their analysis establishes differences between complete configurations. Chao et al., 2020, examine energy aware routing in disaster response networks and demonstrate tradeoffs between delivery and resource objectives. Together, these contributions establish the relevance of operational and routing decisions, but they also distinguish delivery performance from energy efficiency. A higher delivered proportion cannot, by itself, establish a superior energy or economic outcome.

This analysis addresses a narrower comparison problem within the published scenario evidence. A protocol ranking identifies which configuration performs best, but it does not establish which algorithm benefits most from changing battery service. Similarly, an average difference between feature groups may reflect the algorithms included in those groups. The analytical gap concerns the distinction between paired battery responsiveness, feature contrasts within battery conditions and sensitivity to comparison group composition. Reorganizing the available outcomes around these distinctions permits a descriptive contribution without treating the published scenarios as new independent experiments.

The dataset contains 12 aggregate observations, with each observation representing one algorithm under one battery condition. All empirical outcomes originate from the source published in 2021, within the evidence window from 2010 to 2022. The observations form a paired scenario cross section rather than an annual dataset. Message delivery rate is the published proportion of created messages successfully delivered. Battery strategy distinguishes swapping from charging, while predictability and hop count record whether the source lists those characteristics for each algorithm. These designations identify documented features rather than measured prediction accuracy or realized message hops.

The research purpose is to compare message delivery across battery service strategies and documented routing features in disaster response networks under intermittent connectivity. The central question is how delivery differences vary across these configurations and how their interpretation depends on the comparison design. Three objectives guide the analysis: to compare swapping and charging within each algorithm, to compare predictability groups separately under each battery condition, and to compare hop count groups under the same conditions. An exploratory sensitivity analysis then examines whether feature contrasts change when the timetable-based algorithm is excluded.

The completed comparisons distinguish recurring patterns from composition sensitive results. Swapping achieves higher delivery within every algorithm, while predictability group differences vary substantially between battery conditions. The hop count contrast changes direction when the timetable-based algorithm is excluded. The contribution is therefore a structured reanalysis showing why operational responsiveness and routing feature comparisons require different interpretations. For decisions involving comparable aerial networks, the findings support evaluating battery service alongside the complete routing configuration. Their broader relevance lies in this comparison principle, while the numerical magnitudes remain specific to the published simulation setting.

2. Theory, Conceptual Framework and Research Questions Development:

Intermittent connectivity makes message delivery depend on the sequence of contacts between mobile devices and fixed transfer points. A message may remain in storage until a suitable relay becomes available, so delivery requires coordination across time rather than a continuously connected path. Cao and Sun, 2013, explain this process through the store, carry and forward principle, which provides the theoretical foundation for communication under network disruption. This analysis applies that principle to disaster response networks, where battery service and routing decisions jointly shape opportunities for message transfer.

The focal construct is edge coordination configuration, represented by battery service strategy, predictability-based routing and hop count-based routing. The outcome is message delivery rate, defined as successfully delivered messages divided by created messages. These dimensions describe different constraints within the same communication system. Battery service affects node availability, predictability informs relay selection, and hop count informs message prioritization. Their potential benefits depend on available contact opportunities and storage capacity. Silva et al., 2015, identify congestion control as a central challenge in networks without assured connectivity. This establishes a competing mechanism: forwarding decisions may create additional delivery opportunities while increasing competition for limited buffers.

Battery service strategy determines how an aerial relay restores the energy needed to resume operation. Charging requires a period of inactivity, whereas swapping replaces the depleted battery before the next flight. The theoretical expectation is that shorter service interruptions preserve more contact opportunities between drones and transfer points. A message can then progress through the network before its delivery opportunity disappears. This mechanism concerns continuity of relay availability rather than the amount of energy stored in a battery.

Greater availability does not guarantee a proportional improvement in delivery. Additional flights can produce limited benefits when routing decisions fail to use the resulting contacts or when message storage constrains transmission. Chao et al., 2020, demonstrate that energy efficiency and delivery performance involve tradeoffs in disaster response networks. Their evidence supports examining battery service alongside routing configuration rather than treating energy management as an isolated determinant. The available data permit a direct descriptive comparison between swapping and charging within each of the six algorithms.

RQ1: How does message delivery rate differ between battery swapping and battery charging within each routing algorithm?

Predictability based routing addresses uncertainty about which relay offers a useful onward connection. Its conceptual mechanism is selective forwarding: information about delivery prospects guides messages toward

relays expected to encounter suitable destinations or intermediaries. When contact patterns contain useful regularities, informed selection may reduce transmissions that consume storage without improving delivery prospects. Battery service therefore concerns whether a relay is available, while predictability concerns how the network uses an available relay.

The value of predictability depends on how well the information represents subsequent contacts. Historical encounters may offer limited guidance when mobility changes or when a scheduled route provides more useful information. Sobin et al., 2016, distinguish routing approaches through their forwarding information and replication practices, showing why protocol performance must be understood within its application setting. This analysis consequently compares algorithms according to whether predictability appears among their documented characteristics. That classification records a published feature designation rather than a continuous measure of prediction accuracy.

RQ2: How do message delivery rates differ between algorithms with and without a listed predictability feature under each battery service strategy?

Hop count-based routing concerns the use of message traversal history in forwarding or buffer decisions. Its theoretical relevance arises from competition between messages that have already consumed network resources and messages awaiting an opportunity to progress. Prioritization can preserve capacity for selected messages, but the resulting delivery pattern depends on the full scheduling and buffer policy. Hop count alone therefore does not imply a uniform direction of association with delivery rate.

Udroiu et al., 2021, list hop count among the characteristics of MaxProp and MaxDelivery and report delivery rates for both battery service conditions. Their published classifications and scenario outcomes provide the empirical basis for examining this dimension. This analysis records whether hop count is listed as an algorithm characteristic. It does not interpret that designation as the observed number of transfers completed by a message. The resulting comparison concerns algorithm groups whose other features also differ.

RQ3: How do message delivery rates differ between algorithms with and without a listed hop count feature under each battery service strategy?

The conceptual framework links three observed configuration attributes to one observed delivery outcome. Battery service strategy captures the operational condition, while predictability and hop count capture documented routing characteristics. These attributes remain separate categorical measures rather than indicators of a latent scale or components of a combined index. The framework guides descriptive comparisons across 12 published algorithm and battery scenarios. RQ1 compares battery conditions within algorithms. RQ2 and RQ3 compare feature groups separately within each battery condition. These exploratory questions were developed after identifying the available dataset and specify comparisons rather than causal effects.

3. Data:

This analysis consolidates published simulation outcomes into a traceable dataset of routing algorithms and battery service conditions. The data structure supports descriptive comparisons through explicit sample boundaries, documented feature coding and reproducible calculations.

3.1 Data Sources, Population, and Sample Construction:

The empirical source is the published article by Udroiu et al., 2021, available through the publisher and PubMed Central under repository identifier PMC8196586 and DOI 10.3390/s21113572. The article carries a Creative Commons Attribution 4.0 licence. Table 2 supplies algorithm characteristics, while Table 6 supplies delivery outcomes under battery swapping and charging. These table identifiers define the source version used for extraction. Publication year identifies the evidence date rather than a historical observation period. Access metadata remain separate from the analytical variables.

The unit of analysis is one algorithm under one battery service condition. Six algorithms observed under two conditions produce 12 scenario records. The empirical setting is simulated aerial communication for disaster response under intermittent connectivity. Preliminary flight measurements originated in Romania, but the analytical records represent a simulated network rather than geographical observations of disaster events. The publication falls within the eligibility window from 2010 to 2022. The dataset is a paired scenario cross section, with each algorithm represented under swapping and charging. Delivery rates are scenario proportions, not annual flows, stocks or growth rates.

The conceptual target population comprises disaster communication configurations using mobile aerial relays. Its size is not enumerated. The accessible sampling frame consists of the six algorithms and their two battery conditions reported in the source tables. Selection retains every available combination with a delivery rate and a documented algorithm classification. These boundaries were established during dataset construction. The analysis does not represent a probability sample of all disaster communication networks.

Table 1: Sample construction

Stage	Units	Observations	Reason or Rule
Accessible eligible frame	6 algorithms	12 scenarios	Two battery conditions for each algorithm

Stage	Units	Observations	Reason or Rule
Exclusions during extraction	0 algorithms	0 scenarios	All eligible combinations contained the required fields
Consolidated sample	6 algorithms	12 scenarios	Algorithm characteristics linked to scenario outcomes
Records removed during quality checks	0 algorithms	0 scenarios	No missing analytical fields or duplicate scenario keys
Final descriptive sample	6 algorithms	12 scenarios	Complete coverage for all three research questions

The paired structure preserves algorithm identity when comparing battery conditions. This is consistent with the importance of distinguishing routing approaches by their information requirements and forwarding behaviour, as explained by Cao and Sun, 2013. Feature comparisons retain the complete scenario sample and distinguish battery conditions explicitly.

3.2 Data Integration, Cleaning, and Quality Assurance:

Integration linked algorithm characteristics to delivery outcomes through algorithm identity. Each algorithm has one feature classification and two outcome records, producing the intended relationship of one classification to two scenarios. The resulting dataset contains 12 unique record identifiers and 12 unique algorithm and battery combinations. Repeated algorithm names represent the paired design rather than duplicate observations. No unmatched records or unexpected increases in the observation count arose.

Source priority follows the numbered tables. Where adjacent narrative descriptions conflict with Table 6, the extracted values retain the table entries. This rule preserves a consistent extraction basis without selecting values according to their apparent agreement with theoretical expectations. The analysis neither averages conflicting descriptions nor substitutes values from figures.

Quality checks confirmed that delivery rates lie between zero and one and that all three coded predictors contain only zero or one. Every algorithm appears once under each battery condition. Missingness is zero for delivery rate, battery strategy, predictability designation and hop count designation across all 12 records. No deletion, imputation, interpolation or replacement of missing observations was required. The largest delivery rate, 0.973, remains unchanged because it is a reported scenario outcome within the admissible range.

No frequency conversion, temporal matching or monetary adjustment applies to these scenario records. Publication year remains a source identifier rather than an explanatory time variable. The dataset preserves the published precision of delivery rates. Routing and congestion research establishes why performance depends on interacting resource constraints, but it does not supply additional observations for this analysis. Silva et al., 2015, therefore inform interpretation rather than data augmentation.

3.3 Variable Measurement, Construction, and Validation:

Edge coordination configuration is operationalized through three separate observed attributes. Battery service strategy distinguishes swapping from charging. Predictability and hop count identify whether the source lists those characteristics for an algorithm. A zero in either feature variable means that the characteristic is not listed in the source classification. It does not establish that the algorithm lacks every related operation.

Message delivery rate is the published ratio of delivered messages to created messages. The analysis retains this ratio without reconstructing message counts. Table 2 provides the variable dictionary.

Table 2: Variable dictionary

Variable or Indicator	Analytical Role	Definition and Construction	Source and Identifier	Unit and Frequency	Transformation and Direction	Missing Value Rule	Coverage and Limitation
Message delivery rate	Outcome	Published proportion of created messages successfully delivered	Source article, Table 6	Proportion per scenario	Unchanged ratio; higher values indicate greater delivery	Complete in retained records	12 scenarios; aggregate outcome
Battery service strategy	Configuration dimension	One for swapping and zero for charging	Source article, Table 6 condition labels	Binary scenario attribute	Categorical coding without an ordinal interpretation	Complete in retained records	Six scenarios per condition
Predictability designation	Configuration dimension	One when predictability is listed and zero otherwise	Source article, Table 2	Binary algorithm attribute repeated across conditions	Higher code identifies listed feature status	Complete in retained records	Two algorithms coded one; designation does not measure predictive accuracy
Hop count designation	Configuration dimension	One when hop count is listed and zero otherwise	Source article, Table 2	Binary algorithm attribute repeated across conditions	Higher code identifies listed feature status	Complete in retained records	Two algorithms coded one; designation does not measure realized message

Variable or Indicator	Analytical Role	Definition and Construction	Source and Identifier	Unit and Frequency	Transformation and Direction	Missing Value Rule	Coverage and Limitation
							hops
Algorithm identity	Pairing identifier	Published routing algorithm name	Source article, Tables 2 and 6	Nominal identifier per scenario	No numerical transformation	Complete in retained records	Six distinct algorithms
Publication year	Provenance identifier	Publication year of the empirical source	Source article metadata	Year	No transformation	Complete in retained records	One publication year, 2021

Predictability is listed for PRoPHET and MaxProp. Hop count is listed for MaxProp and MaxDelivery. These classifications remain separate because they describe different routing features and overlap in only one algorithm. Sobin et al., 2016, distinguish routing approaches through forwarding information and replication practices, supporting the interpretation of these measures as configuration attributes rather than interchangeable indicators of a single scale.

Validation checked permissible values, completeness, scenario uniqueness and consistency between feature codes and the source classification. The measures are observed categories and published proportions. Their interpretation therefore rests on accurate transcription and coding.

Table 3: Descriptive statistics

Variable	Valid Count	Mean	Standard Deviation	Median	Minimum	Maximum
Message delivery rate	12	0.4036	0.2948	0.2660	0.1460	0.9730
Battery swapping indicator	12	0.5000	0.5222	0.5000	0	1
Predictability designation	12	0.3333	0.4924	0	0	1
Hop count designation	12	0.3333	0.4924	0	0	1

The outcome mean gives equal weight to each scenario. It is not a pooled delivery ratio across individual messages. For binary variables, the mean represents the proportion of records coded one. The reported standard deviations describe variation across the retained scenarios rather than uncertainty across independent simulation replications.

3.4 Analytical Framework, Identification, and Reproducibility:

The analytical framework is descriptive. It evaluates differences within the published scenario set using equal scenario weights. Battery strategy is compared within each algorithm, while predictability and hop count designations are compared within each battery condition. This separation preserves the pairing relevant to RQ1 and the conditional comparisons required by RQ2 and RQ3. Chao et al., 2020, show that energy and delivery objectives can involve tradeoffs, reinforcing the need to interpret configuration comparisons within their operating conditions. For RQ1, Equation 1 expresses each paired battery difference in percentage points.

$$\Delta_a = 100 \times \left[Y_{a,S} \backslash \text{mathbin minus } Y_{a,C}\right]$$

Here, Δ_a is the delivery difference for algorithm Δ_a, $Y_{a,S}$is its delivery proportion under swapping, and $Y_{a,C}$is its delivery proportion under charging. Multiplication by 100 converts the difference between proportions into percentage points. Each algorithm contributes one paired difference. For RQ2 and RQ3, Equation 2 calculates the mean delivery proportion for each feature group within a battery condition.

$$\overline{Y}_{jgb} = \frac{\sum_{i \in G_{jgb}} Y_i}{n_{jgb}}$$

Here, $\overline{Y}_{jgb}$ is the mean delivery proportion for feature j, code gand battery condition b. The set G_{jgb} contains records meeting those conditions, Y_i is the published delivery proportion for record i, and n_{jgb} is the number of included records. Feature jdenotes predictability or hop count, while gtakes the value zero or one. Equation 3 expresses the corresponding feature group contrast in percentage points.

$$D_{jb} = 100 \times \left[\overline{Y}_{j,1,b} \backslash \text{mathbin minus } \overline{Y}_{j,0,b}\right]$$

Here, D_{jb} is the difference between the mean delivery proportions of the two feature groups under battery condition b. Each condition contains two algorithms with a listed feature and four without that designation.

The calculations describe observed scenario contrasts. Battery comparisons hold algorithm identity constant, while feature comparisons involve algorithms with other configuration differences. Consequently, the feature contrasts cannot isolate the contribution of a single routing characteristic. Shared simulation conditions also mean that the 12 records should not be interpreted as independent network deployments.

Reproducibility rests on stable source identifiers, numbered source tables, explicit binary coding, unique scenario keys and unchanged published outcomes. The workbook retains the extracted records, definitions and formula based comparisons. The descriptive calculations use the same 12 scenarios throughout, with no changes to eligibility or variable coding during this analysis.

4. Methods:

4.1 Research Design and Comparison Strategy:

This analysis uses a descriptive reanalysis of published simulation outcomes to compare message delivery across operational and routing configurations. The unit of analysis is one algorithm under one battery service condition. Six algorithms observed under swapping and charging provide 12 scenario records. The design uses variation between battery conditions within algorithms and variation between documented feature groups within each condition. The source simulations and algorithm classifications are reported by Udroiu et al., 2021.

Three comparisons answer the research questions. The first measures the delivery difference between battery conditions for each algorithm. The second compares algorithms with and without listed predictability under each condition. The third applies the same comparison to the hop count designation. Battery condition provides an observed grouping factor rather than an estimated moderator.

The paired comparison preserves algorithm identity, reducing ambiguity arising from differences between routing configurations. Feature comparisons involve different algorithms whose other characteristics also vary. They therefore describe differences between configuration groups rather than isolate the contribution of an individual feature. Routing taxonomies distinguish algorithms through combinations of forwarding information and operational rules, supporting this interpretation of the comparison groups, as explained by Cao and Sun, 2013.

The analytical targets are finite sample differences in published delivery proportions. The design does not assign probabilities to treatment selection or identify a causal effect. Its explanatory value comes from distinguishing paired operational comparisons from comparisons involving different algorithm compositions.

4.2 Analytical Specification and Measurement Alignment:

The sample construction table and variable dictionary define the retained scenarios and measurement rules. All 12 records enter the primary comparisons. Each algorithm contributes one observation under each battery condition, giving equal representation across the paired design. The analytical sample is a complete enumeration of the available combinations in the selected source tables.

Delivery remains on its published proportion scale. Multiplication by 100 expresses a proportion as a percentage, while multiplication of a difference between proportions by 100 expresses a percentage point contrast. Calculations use the original proportions before rounding.

Equation 1 defines the paired swapping difference for each algorithm. Its outcome is positive when swapping produces greater delivery than charging. The analysis summarizes the six differences through their arithmetic mean, median and range. Each algorithm receives equal weight, so the mean represents average responsiveness across algorithms rather than a pooled message delivery rate.

Equation 2 defines the arithmetic mean within each routing feature group and battery condition. Predictability and hop count are examined separately. For each designation, the group coded one contains two algorithms under each battery condition, while the group coded zero contains four. Equation 3 subtracts the mean for the group coded zero from the mean for the group coded one and expresses the contrast in percentage points.

Feature codes follow the published classification. One indicates that the characteristic is listed, and zero indicates that it is not listed. The codes do not measure prediction accuracy, realized route length or feature intensity. MaxProp belongs to both designated feature groups. Separate comparisons preserve this overlap without treating the attributes as independent experimental interventions.

4.3 Processing, Calculation and Verification:

Processing began with the populated scenario records. Verification established the uniqueness of record identifiers and algorithm and battery combinations. It also checked that every algorithm appeared under both battery conditions, feature codes contained only zero or one, and delivery proportions remained within the admissible interval from zero to one. These checks retained all 12 observations.

Published table entries took priority where adjacent narrative descriptions differed from the tabulated outcomes. No interpolation, imputation or replacement of missing values was applied. All required analytical fields were complete. Valid extreme outcomes remained in the dataset without trimming or winsorization.

Descriptive calculations used Python version 3.12.14 and its standard statistics module. Workbook records were read through the zipfile and xml.etree. Element Tree modules. The calculations produced valid counts, arithmetic means, medians, minima, maxima and sample standard deviations. Standard deviations used the number of observations minus one as the denominator. These statistics describe dispersion across scenarios rather than uncertainty across independently replicated simulation runs.

The analytical sequence first summarized the complete sample, then calculated paired battery differences, followed by feature group means within each battery condition. Group contrasts were obtained from unrounded means. Displayed results were rounded only after calculation.

The workbook preserves source identifiers, scenario records, coding definitions and formula-based summaries. Python calculations independently reproduced the paired battery differences and pooled feature

means and extended the comparisons by separating battery conditions. This verification checked arithmetic consistency without introducing additional observations.

4.4 Sensitivity Analysis, Interpretation and Reproducibility:

An exploratory restriction examined sensitivity to the inclusion of TD UAV Dijkstra. This algorithm uses a timetable-based configuration and belongs to both groups without the listed routing features. Its exclusion therefore directly changes the composition of the comparison groups. The restriction was selected after inspecting the complete sample and is identified as exploratory.

The procedure removed both battery observations for that algorithm, retaining five algorithms and ten scenarios. Equations 1 to 3 were then applied without changing outcome values, coding rules or weighting. For the battery comparison, the procedure recalculated the mean paired difference across the five retained algorithms. For each feature comparison, it retained the two designated algorithms and reduced the comparison group from four algorithms to three within each battery condition.

Sensitivity was assessed through changes in direction and magnitude. The restricted analysis was compared with the complete sample to determine whether a pattern depended on the timetable-based configuration. Because the observations themselves remained unchanged, differences between the two analyses reflect sample composition.

Reproduction requires the scenario dataset, its source table identifiers, the published feature classification and Equations 1 to 3. The calculations are deterministic and require no random initialization. The design answers the research questions through transparent comparisons of the available records. Its methodological contribution lies in separating operational responsiveness from composition sensitive feature contrasts using established descriptive procedures.

5. Findings:

This analysis examines message delivery across battery service strategies and documented routing features. It first establishes the distribution of delivery outcomes, then answers the three research questions through paired and grouped comparisons. An exploratory sensitivity check assesses how the timetable-based algorithm influences feature group differences.

5.1 Sample Characteristics and Delivery Distribution:

The analytical sample contains 12 published scenarios covering six routing algorithms under battery swapping and charging. Each algorithm contributes one observation per battery condition. All records contain the delivery outcome and three configuration attributes, with no exclusions or missing analytical values. The observations represent aggregate simulation outcomes reported in 2021 rather than independent disaster deployments. Algorithm classifications and delivery proportions originate from Tables 2 and 6 of Udroiu et al., 2021.

Across the 12 scenarios, mean delivery was 40.36%, the median was 26.60%, and the sample standard deviation was 29.48 percentage points. Delivery ranged from 14.60% to 97.30%. The mean exceeded the median because several configurations achieved substantially higher delivery than the remaining scenarios. This dispersion makes algorithm specific comparisons more informative than the overall average alone.

Battery conditions were evenly represented, with six observations each. Predictability was listed for two algorithms, producing four scenario records, while hop count was listed for two algorithms, also producing four records. These feature groups overlap through MaxProp. Their comparisons therefore describe bundled configurations rather than isolated routing mechanisms. This interpretation follows the distinction between forwarding information and replication practices developed by Sobin et al., 2016.

5.2 Battery Service Strategy and Message Delivery:

Battery swapping produced higher delivery than charging for every algorithm. Mean delivery increased from 28.43% under charging to 52.28% under swapping, giving an average paired difference of 23.85 percentage points. The median paired difference was 21.00 percentage points. The consistent direction answers RQ1, while the variation in magnitude shows that the delivery advantage depended on routing configuration.

Table 4: Paired delivery comparisons by battery service strategy

Algorithm	Swapping Delivery %	Charging Delivery %	Swapping Advantage in Percentage Points
Epidemic	20.90	14.60	6.30
Spray and Wait	17.90	15.60	2.30
PRoPHET	76.20	31.90	44.30
MaxProp	74.30	26.10	48.20
MaxDelivery	27.10	16.00	11.10
TD UAV Dijkstra	97.30	66.40	30.90
Equal algorithm mean	52.28	28.43	23.85

MaxProp recorded the largest battery difference at 48.20 percentage points, followed by PRoPHET at 44.30 percentage points. Spray and Wait recorded the smallest difference at 2.30 percentage points. The timetable-based algorithm achieved the highest delivery under both conditions, but it did not show the largest swapping advantage. Absolute delivery performance and responsiveness to battery strategy therefore represent distinct empirical patterns.

These results are consistent with the proposition that operational availability and routing decisions jointly shape delivery. They do not measure energy efficiency directly. Chao et al., 2020, identify tradeoffs between energy use and delivery performance in disaster response networks, supporting this separation between the measured delivery outcome and broader resource efficiency.

5.3 Predictability and Hop Count Comparisons:

Algorithms with listed predictability achieved mean delivery of 75.25% under swapping, compared with 40.80% for algorithms without that designation. The difference was 34.45 percentage points. Under charging, the corresponding means were 29.00% and 28.15%, giving a difference of 0.85 percentage points. RQ2 is therefore resolved by a positive descriptive contrast whose magnitude differs substantially between battery conditions.

Table 5: Delivery comparisons by documented routing feature

Feature	Battery Condition	Algorithms With Feature	Algorithms Without Feature	Mean With Feature %	Mean Without Feature %	Descriptive Contrast
Predictability	Swapping	2	4	75.25	40.80	Feature group higher by 34.45 percentage points
Predictability	Charging	2	4	29.00	28.15	Feature group higher by 0.85 percentage points
Hop count	Swapping	2	4	50.70	53.08	Feature group lower by 2.38 percentage points
Hop count	Charging	2	4	21.05	32.13	Feature group lower by 11.08 percentage points

The predictability comparison shows why pooling battery conditions would conceal relevant variation. A pooled average would combine a pronounced group difference under swapping with a small difference under charging. The available records establish this conditional pattern without identifying a separate predictability effect. Cao and Sun, 2013, explain that routing performance depends on the information available to forwarding decisions and the connectivity setting, which is consistent with interpreting these results within their operating conditions.

Algorithms with listed hop count achieved lower group means under both battery conditions. Their mean delivery was 50.70% under swapping, compared with 53.08% among the remaining algorithms. Under charging, the corresponding means were 21.05% and 32.13%. RQ3 is answered by lower observed delivery in the hop count group within the complete sample.

The group average nevertheless conceals substantial variation. MaxProp and MaxDelivery both carry the hop count designation, yet their swapping delivery rates were 74.30% and 27.10%. A shared designation therefore did not correspond to similar delivery performance. This difference supports treating hop count as one documented configuration feature rather than a sufficient explanation of performance. Silva et al., 2015, identify the interaction between routing and congestion management as central to constrained networks, providing a relevant explanation for why a single feature classification need not determine the outcome.

5.4 Sensitivity to Algorithm Composition and Research Question Resolution:

An exploratory sensitivity checks excluded TD UAV Dijkstra because its timetable-based configuration differs from the other algorithms. The restriction retained five algorithms and ten scenarios. It tested whether feature group contrasts depended on including the highest performing algorithm in both groups without the listed features. The exclusion was introduced after inspecting the complete sample and does not replace the primary comparisons.

The battery result retained its direction for all five remaining algorithms. Their mean paired swapping advantage was 22.44 percentage points, compared with 23.85 percentage points in the complete sample. The positive battery comparison therefore did not depend on the timetable-based algorithm.

Predictability contrasts also remained positive. After the exclusion, algorithms without listed predictability achieved mean delivery of 21.97% under swapping and 15.40% under charging. The

corresponding predictability advantages increased to 53.28 and 13.60 percentage points. Their direction persisted, but their magnitudes depended on which algorithms formed the comparison group.

The hop count comparison changed direction. After excluding the timetable-based algorithm, the group without listed hop count averaged 38.33% under swapping and 20.70% under charging. The hop count group then exceeded those means by 12.37 and 0.35 percentage points. The lower delivery observed for the hop count group in the complete sample was therefore sensitive to algorithm composition.

The evidence resolves RQ1 through a consistent swapping advantage across all six paired comparisons. It resolves RQ2 through positive predictability group contrasts that vary by battery condition and comparison group composition. It resolves RQ3 through a composition sensitive contrast whose direction reverses under the exploratory restriction. These findings establish descriptive differences within the published scenarios, with the clearest recurring pattern arising from the battery comparison within algorithms.

6. Discussion:

Operational continuity emerges as the most consistent basis for comparing delivery performance in these scenarios. Table 4 and Equation 1 show a swapping advantage within every algorithm, while its magnitude varies substantially across routing configurations. The distinction between absolute performance and responsiveness is central: the timetable-based algorithm achieves the highest delivery, but MaxProp records the largest battery difference. The contribution of this reanalysis is to separate these two dimensions of performance within the published results of Udroiu et al., 2021. An algorithm that ranks highest under a given operating condition does not necessarily benefit most from changing that condition. This shifts interpretation from a single protocol ranking toward the joint evaluation of routing configuration and battery service.

The predictability comparison reveals a conditional pattern that the pooled feature average obscures. Table 5, interpreted through Equations 2 and 3, shows a pronounced predictability group advantage under swapping and a much smaller contrast under charging. Operational availability offers a plausible explanation: information about useful contacts may have limited practical value when relays remain unavailable to exploit them. This interpretation extends the forwarding distinctions reviewed by Sobin et al., 2016, by showing why feature comparisons require explicit attention to battery conditions. The evidence identifies variation consistent with that explanation, rather than measuring the intervening contact process. Its analytical contribution is therefore the separation of operating conditions under which the same documented feature corresponds to different delivery contrasts.

Hop count provides the clearest warning against interpreting a routing designation as an independent performance attribute. Table 5 shows lower delivery for algorithms carrying that designation in the complete sample, yet the exploratory exclusion reverses the contrast under both battery conditions. Equation 3 makes the source of this reversal transparent: changing the algorithms in the comparison group changes its mean, even though the retained algorithms and their outcomes remain unchanged. This result adds a composition boundary to the interpretation of routing classifications. Cao and Sun, 2013, organize routing approaches around different information and forwarding requirements; the present comparisons demonstrate why those categories cannot be treated as interchangeable performance treatments. The theoretical implication is that configuration membership and comparison group composition must accompany any claim about a feature advantage.

The practical implication is to evaluate battery service and routing as a combined configuration while preserving separate performance criteria. Table 4 shows that the highest delivery level and the largest battery responsiveness belong to different algorithms. Decision makers examining comparable networks should therefore compare both the attainable delivery level and the within algorithm difference defined by Equation 1. The evidence supports assessing swapping as a delivery option across the tested algorithms, but it does not establish its economic or energy superiority. Chao et al., 2020, explicitly examine tradeoffs between energy and delivery objectives in disaster response networks. Read alongside that work, these findings clarify why a delivery improvement should guide configuration assessment without being converted into a broader claim of resource efficiency.

The international relevance lies in a comparison principle that applies wherever intermittent communication combines constrained relay availability with heterogeneous routing policies. Silva et al., 2015, frame congestion management as a network problem involving interacting resource constraints. The present reanalysis contributes a complementary empirical distinction: the battery contrast remains positive after the exploratory restriction, whereas the hop count contrast changes direction. Tables 4 and 5 and Equations 1 to 3 therefore distinguish a recurring paired pattern from a composition sensitive group pattern. This is an analytical contribution within one published simulation setting, rather than a geographical comparison. Further evaluation should examine whether these contrasting patterns persist across network layouts and independently replicated runs, with contact availability measured directly to assess the proposed operational explanation.

7. Conclusion and Implications:

Emergency communication requires coordination between operational continuity and forwarding decisions. This analysis shows that improved availability accompanies better delivery across the examined configurations, while advantages associated with routing characteristics depend on operating conditions and

comparison group composition. Its contribution is to distinguish a recurring operational pattern from feature comparisons that change when the benchmark changes. This distinction refines the interpretation of communication networks by showing why the highest performing configuration need not benefit most from an operational adjustment. The evidence therefore supports a conditional understanding of performance rather than a universal ranking of individual features. Managers should evaluate complete configurations, compare alternatives under equivalent operating conditions, and separate attainable performance from responsiveness to operational changes. Resource allocation decisions should consider continuity arrangements alongside routing choices, while reserving judgments about cost and energy efficiency for evaluations that measure them directly. Procurement and emergency preparedness policies can apply this principle through scenario-based assessment and explicit benchmark selection. Operational teams can strengthen evaluation routines by preserving paired comparisons and checking whether conclusions depend on exceptional configurations. Beyond the examined setting, this framework offers a disciplined basis for assessing communication options whose dependable operation could support emergency coordination and access to essential information.

The evidence comprises aggregate scenarios from one published simulation setting, creating opportunities for validation across broader network designs. Independently replicated simulations should vary topology, contact schedules and resource constraints while retaining comparable operational alternatives. Recording contact availability and message trajectories would permit direct examination of the proposed transmission process. Field evaluations across emergency environments could assess transferability beyond controlled conditions. Future comparisons should also measure service costs, energy consumption and deployment requirements to connect delivery performance with implementation decisions. These extensions would establish when the observed patterns persist and whether configuration differences reflect specific mechanisms or broader operational conditions.

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